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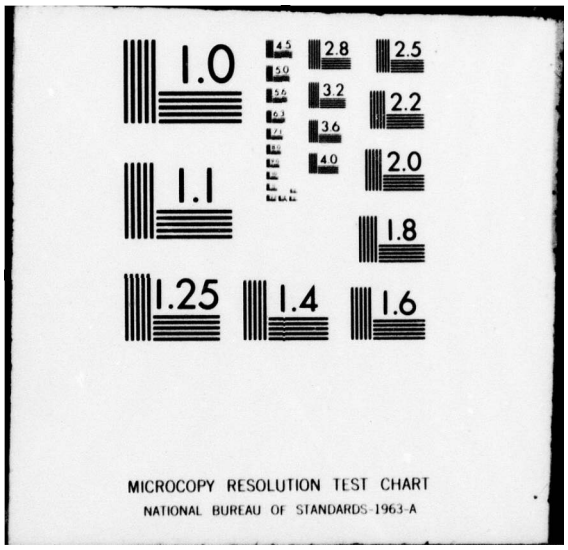
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GROWTH RATES AND CHARACTERISTICS OF ICE ON THE OTTAUQUECHEE AND WINOOSKI RIVERS OF VERMONT DURING WINTER 1977-78.

(10) David Deck

(15) DACA89-78-C-0090

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DEPARTMENT OF THE ARMY
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CORPS OF ENGINEERS
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Ice thickness, growth rates and characteristics of river ice are tabulated for use with a planned physical hydraulic model of the Ottauquechee River in Quechee, Vt., using real ice.

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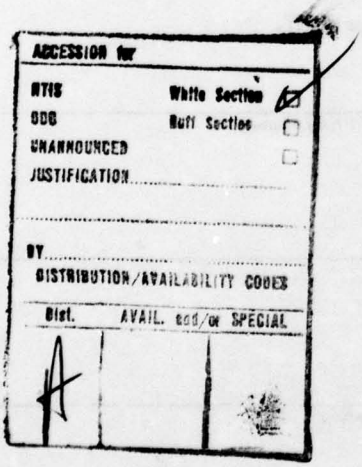
PREFACE

This data report was prepared by David Deck under Contract DACA-89-78-0990 with the U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded by the Directorate of Civil Works, Office, Chief of Engineers.

The ice thickness data reported here were collected by Darryl Calkins, David Deck and Carl Martinson in conjunction with a planned model study of the Ottauquechee River. Additional data will be made available on ice cover progression, water levels, water temperature regime and ice decay, frazil ice, ice jams and remote measurements of ice jams.

Technical review of this report was performed by Darryl Calkins and James Wuebben of CRREL.



INTRODUCTION

During the 1977-78 winter season the growth rates and characteristics of the ice cover were observed on two Vermont rivers, the Ottauquechee River in Quechee and the Winooski River in Middlesex and Montpelier. These observations included measurement of the solid ice and also the amount, if any, of frazil slush ice under the solid cover. The large amounts and the effects of frazil slush produced some interesting and unsuspected data (see Discussion). The river ice thickness data presented in this report will be used in conjunction with a model study of ice jams at the CRREL Ice Engineering Facility.

Appendices A, B and C contain ice thickness data for the two rivers. Appendix D contains representative graphs of ice thickness (η_1) growth rates at selected sites during the third freeze-up of the Ottauquechee River.

TEST SITES

A portion of the Ottauquechee River near Quechee, Vermont, was the site of the field measurements (Fig. 1). The reach of river studied begins at John Downers Dam in Quechee and continues upstream for approximately 3.2 km (2 miles). This reach consists of 52 cross sections, or stations, 61 m (200 ft) apart, of which 11 cross sections were monitored. The river was surveyed in the summer of 1975, with the dam being designated as 11+00. This survey began 670 m (2200 ft) downstream of the studied reach of river.

The limited ice thickness measurements taken on sections of the Winooski River will be used primarily as a check on a flood prediction report for an ice jam at Middlesex.

The backwater from the Quechee dam during typical winter flow conditions (300 ft^3/s) (8.5 m^3/s) extends up to station 24+00 with a slope in the order of magnitude of 10^{-4}. The remainder of the site has an overall slope of 10^{-3} and includes four rapids sections. These short fast-water reaches have slopes as steep as 10^{-2}.

FREEZE-UP

Three separate ice cover formations occurred on the Ottauquechee in the 1977-78 winter. Shore ice began forming in early December and the initial cover was formed on the morning of 10 December as the frazil slush ice arched over at station 15+00 (Fig. 2-4). The cover quickly progressed upstream to station 30+00 by late afternoon. On the 11th the

cover moved upstream near station 45+00. This initial cover was lost after a severe rain on 8-9 January (Fig. 5). Ice was again formed, in a similar manner, on the 20th. Rain on the 25th caused the cover to jam between stations 15+00 and 22+00, with a new cover beginning to form the same day. This final cover remained until spring melting caused it to go out on 31 March, with no ice jams resulting. The average daily temperatures at Woodstock, Vermont, are plotted in Figures 6 and 7 for the first and third freeze-ups.

EQUIPMENT AND PROCEDURE

Holes were drilled through the ice with a 5.72-cm (2 1/4-in.) auger at selected cross sections at various distances from the river bank (Fig. 8,9). The solid ice was measured with a thickness gauge capable of giving an accuracy to 1/8 in.

Frazil slush ice was detected by four different methods.

1. Visual. Slush ice could be readily detected through observation of the ice crystals when the hole was being cleared with the auger, but this gave no idea of the thickness.

2. Vane current meter. A meter was lowered down through the slush until it gave indication of a flow velocity, just below the slush ice/free fluid interface, then raised until a zero flow was recorded. The trouble with this type of detection was that the equipment was mechanical and froze up in low air temperatures and malfunctioned if left outside of the fluid environment. The method was also time-consuming.

3. Magnetic current meter. The same procedure was used as with the vane meter but there were no moving parts in the fluid and no icing problems. Again the method was time-consuming.

4. Impulse radar technique. An impulse radar unit was used to detect solid ice, slush ice, and water interfaces. The unit can be towed across the ice cover behind a snowmobile or by hand. This method was fast and preliminary data show it to be the best means for detecting slush ice.

DISCUSSION

The data are more consistent at some sites than at others because of precise tape-measuring to the same holes from a constant reference. During the first freeze-up, stations 12+00 and 15+00 had all holes drilled in the exact locations designated. The same is true of stations

49+00, 50+50 and 53+00 during the third freeze-up. Holes at the other stations may have been drilled within ±1 m on a few occasions, mainly because a heavy snow cover sometimes made it very difficult to find the exact location of the previous hole.

It is believed that greater quantities of solid ice will form in areas where there are large amounts of frazil slush under the solid ice cover than in slush-free areas. The slush ice is already in between the liquid and solid states of water and therefore requires less heat to be removed to form solid ice. The slush ice appears to become a greater factor as the solid cover becomes thicker and it takes a longer time for the heat to be extracted from the ice cover.

Slush ice was also observed to greatly reduce the melting of the underside of the solid ice cover when water temperatures rose to +0.1 to +0.4°C beneath the cover. This is very clear in all the graphs of ice thickness duration in Appendix D. As long as the slush ice remained under the cover it retarded the melting process so that only ice/air surface melting occurred.

This further supports the importance of the role frazil slush ice is performing. The heat from the water that would otherwise be conducted and convected to the solid cover is first used to melt the frazil slush. The areas of frazil slush beneath the cover generally had low flow velocities, again reducing the heat transfer rate.

The following brief summary, for non-slush and slush holes exclusively, shows the increased extent of solid ice growth due to frazil slush beneath the cover.

Sta. 12+00 - 6 Jan 78

65'*Lt. - slush ice
444 mm solid ice (17.5 in.)

104'*Lt. - no slush
419 mm solid ice (16.5 in.)

6% greater growth in slush hole. This began to increase before the cover was lost on the 9th.

Sta. 49+00 - 9 Mar 78

118'Rt. - slush ice
559 mm solid ice (22 in.)

58'Rt. - no slush
384 m solid ice (15.1 in.)

31% greater growth in slush hole.

142'Rt. - slush ice
635 mm solid ice (25 in.)

60% greater growth than in slush-free hole.

*Distance from left (Lt.) or right (Rt.) river bank, looking upstream.

Sta. 50+50 - 2 Mar 78

55'Rt. - slush ice
508 mm solid ice (20 in.)

40'Rt. - no slush
375 mm solid ice
(14.75 in.)

26% greater growth in slush hole.

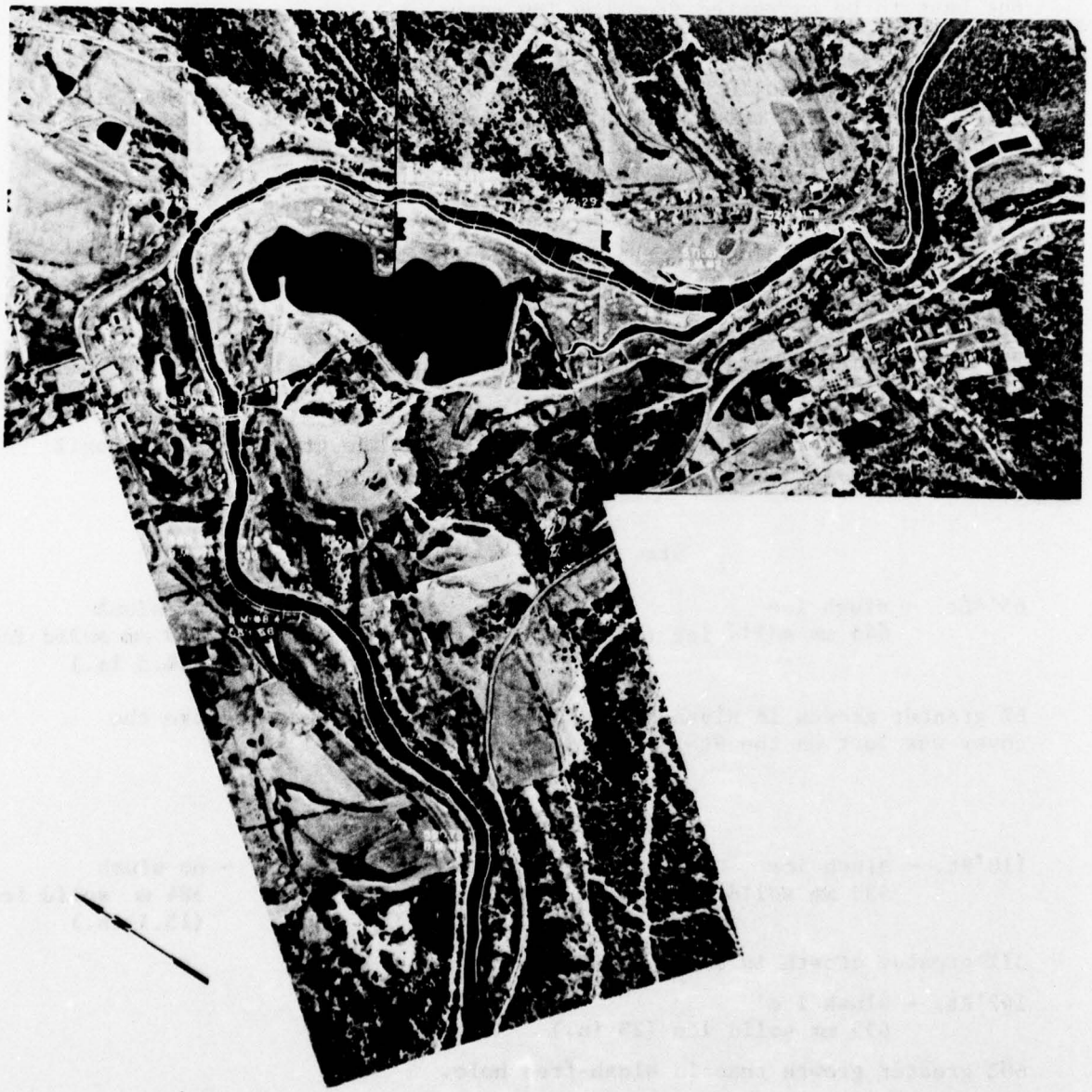


Figure 1. Ottauquechee River showing locations of cross sections.

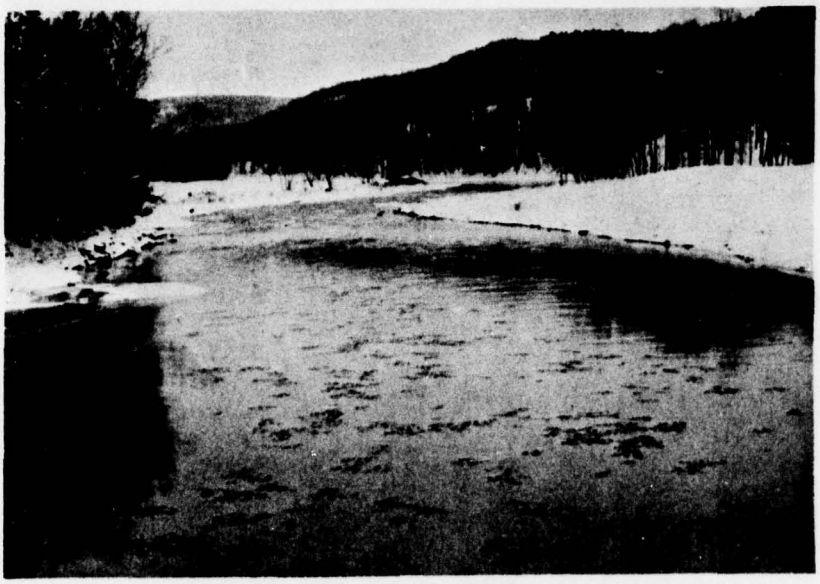


Figure 2. Frazil ice generated in supercooled water near station 55+00, 19 Dec 77.

Figure 3. Ice conditions at station 15+00 prior to arching of initial cover, 9 Dec 77.

Figure 4. Frazil ice going under solid cover at station 53+00, 19 Dec 77.

Figure 5. Ice run of 9 Jan 78 observed at John Downer's Dam.

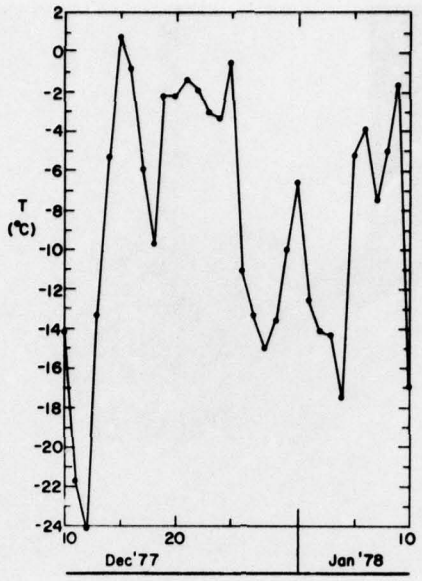


Figure 6. Average daily temperatures in Woodstock, first freeze-up.

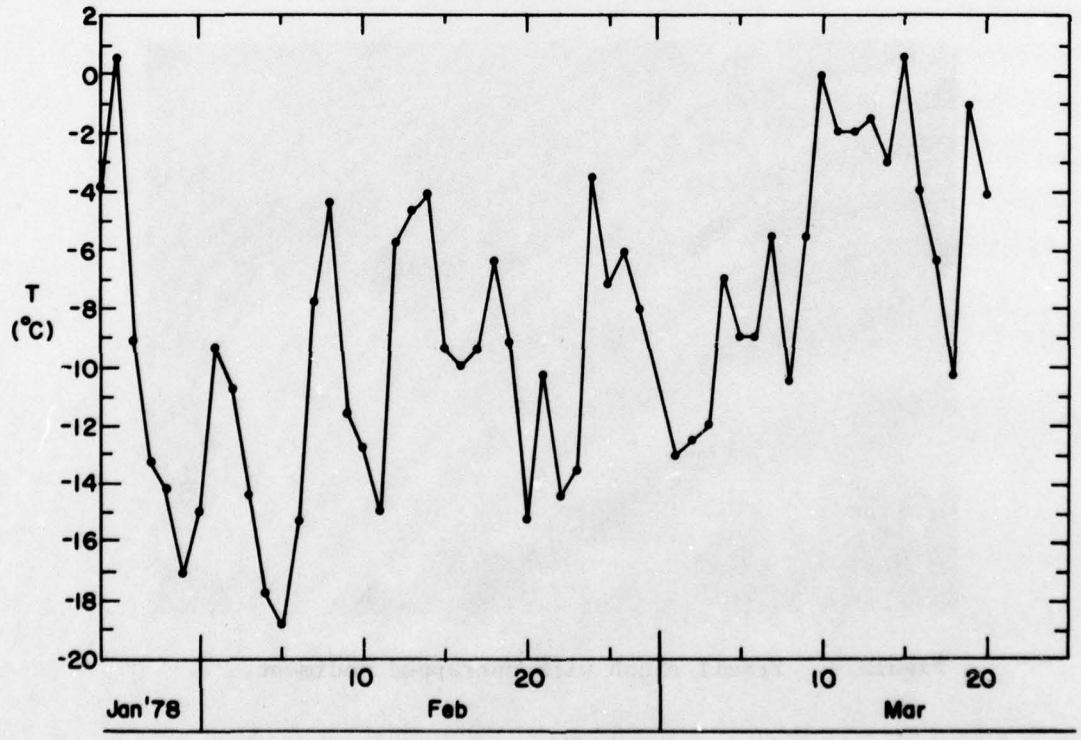


Figure 7. Average daily temperatures in Woodstock, first freeze-up.

Figure 8. Typical ice auger hole with extracted frazil slush around perimeter.

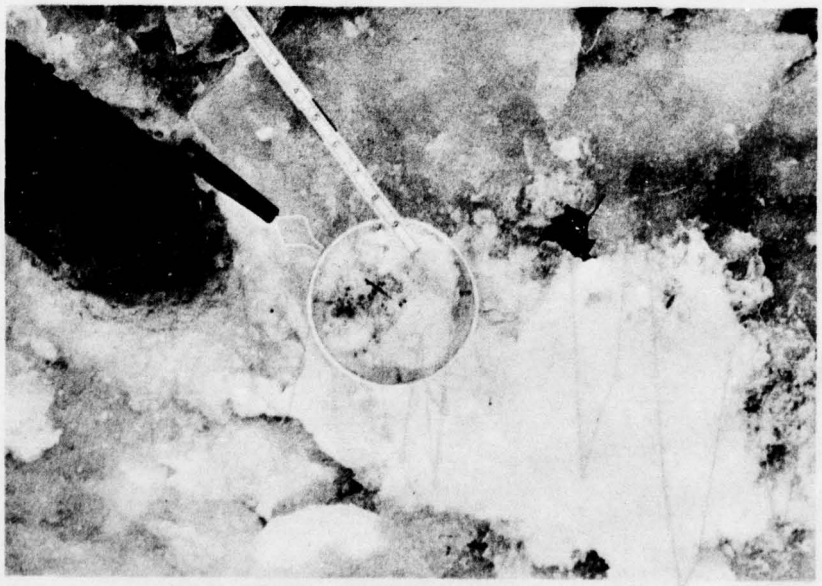


Figure 9. Frazil slush with entrapped sediment.

APPENDIX A: ICE THICKNESS DATA, OTTAUQUECHEE RIVER, FIRST FREEZE-UP.

OTTAUQUECHEE RIVER

Sta. 12+00

Date	Position* from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-31-77	17'	14.25	361.95			3.19	0.98
1- 5-78		17.00	431.80	0.55	13.97	X	
1- 6-78		17.25	438.15	0.25	6.35	X	
12-27-77	35'	14.00	355.60			X	
12-29-77		15.50	393.70	0.75	19.05	X	
12-31-77		15.50	393.70	0.00	0.00	5.60	1.71
1- 3-78		15.50	393.70	0	0	X	
1- 5-78		18.00	457.20	1.25	31.75	X	
1- 6-78		19.00	482.60	1.00	25.4	X	
12-27-77	65'	10.00	254.00			X	
12-29-77		12.75	323.85	1.38	34.92	X	
12-31-77		14.12	358.65	0.68	17.40	X	
1- 3-78		14.12	358.65	0.00	0.00	X	
1- 5-78		15.00	381.00	0.44	11.18	X	
1- 6-78		17.50	444.50	2.50	63.50	X	
12-15-77	90'	4.12	104.65				
12-22-77		7.00	177.80	0.41	10.45	X	
12-29-77		12.50	317.50	0.79	19.96	X	
12-31-77		13.00	330.20	0.25	6.35	X	
1- 5-78		15.00	381.00	0.40	10.16	X	
1- 6-78		15.50	393.70	0.50	12.70	X	
12-15-77	120'	8.50	215.90				
12-27-77		12.50	317.50	0.33	8.47		
12-29-77		14.62	371.35	1.06	26.92		
12-31-77		15.75	400.05	0.56	14.35		
1- 3-78		15.75	400.05	0	0		
1- 5-78		16.75	425.45	0.50	12.70	X	
1- 6-78		17.00	431.80	0.25	6.35	X	
12-15-77	140'	7.44	188.98				
12-27-77		13.00	330.20	0.46	11.77		
12-29-77		14.50	368.30	0.75	19.05		
12-31-77		15.12	384.05	0.31	7.87		
1- 3-78		15.50	393.70	0.13	3.22		
1- 5-78		16.25	412.75	0.38	9.52		
1- 5-78		16.50	419.10	0.25	6.35		

* = Distance (ft) from Right or Left Bank looking upstream.
X = Frazil slush ice present but quantity unknown.

OTTAUQUECHEE RIVER

Sta. 15+00

Date	Position* from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-29-77	35'	14.00	355.60			X	
12-31-77		15.00	381.00	0.50	12.70	X	
1- 3-78		16.38	416.05	0.46	11.68	X	
1- 6-78		16.75	425.45	0.12	3.13	3.45	1.05
12-27-77	75'	13.25	336.55			X	
12-29-77		15.00	381.00	0.88	22.22	X	
12-31-77		15.50	393.70	0.25	6.35	X	
1- 3-78		16.25	412.75	0.25	6.35	X	
1- 6-78		18.75	476.25	0.83	21.17	1.70	0.52
12-27-77	115'	10.25	260.35			X	
12-29-77		12.00	304.80	0.88	22.22	X	
12-31-77		13.38	339.85	0.69	17.53	X	
1- 3-78		14.62	371.35	0.41	10.50	X	
1- 6-78		15.00	381.00	0.13	3.22	3.6	1.10

OTTAUQUECHEE RIVER

Sta. 18+00

Date	Position* from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-13-77	130'	5.50	139.70			2.0	0.61
12-22-77		8.50	215.90	0.33	8.47	X	
12-27-77		11.00	279.40	0.50	12.70	0	
12-29-77		12.50	317.50	0.75	19.05	0	
12-31-77		13.50	342.90	0.50	12.70	X	
1- 3-78		14.50	368.30	0.33	8.47	0	
12-13-77	180'	7.00	177.80			2.0	0.61
12-22-77		10.00	254.00	0.33	8.47	X	
12-27-77		13.50	342.90	0.70	17.78	X	
12-29-77		14.75	374.65	0.62	15.88	X	
12-31-77		15.88	403.35	0.56	14.35	X	
1- 3-78		16.00	406.40	0.04	1.02	X	
1- 6-78		18.00	457.20	0.67	16.93	X	

OTTAUQUECHEE RIVER

Sta. 25+70

Date	Position* from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-12-77	35'	6.25	158.75			0	0
12-13-77		6.25	158.75	0	0	2.80	0.85
12-22-77		8.00	203.20	0.19	4.94	X	
12-27-77		12.75	323.85	0.95	24.13	X	
12-29-77		13.88	352.55	0.56	14.35	X	
12-31-77		15.00	381.00	0.56	14.35	X	
1- 3-78		16.12	409.45	0.37	9.48	X	
1- 6-78		17.25	438.15	0.38	9.57	X	
12-12-77	80'	8.25	209.55			X	
12-13-77		8.25	209.55	0	0	0.83	0.25
12-29-77		16.75	425.45	0.53	13.49	X	
1- 3-78		18.00	457.20	0.25	6.35	X	
12-12-77	170'	4.00	101.60			X	
12-13-77		4.00	101.60	0	0	1.69	0.52
12-27-77		9.75	247.65	0.41	10.43	X	
12-29-77		11.50	292.10	0.88	22.22	X	
12-31-77		15.38	390.65	1.94	49.28	X	
1- 6-78		20.50	520.70	0.85	21.67	0	
12-27-77	190'	12.50	317.50			X	
12-29-77		14.25	361.95	0.88	22.22	X	
1- 3-78		15.75	400.05	0.30	7.62	X	
1- 6-78		19.00	482.60	1.08	27.52	X	

OTTAUQUECHEE RIVER

Sta. 27+00

Date	Position* from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-13-77	40'	6.25	158.75			5.31	1.62
12-22-77		8.50	215.90	0.25	6.35	X	
12-27-77		12.75	323.85	0.85	21.59	X	
12-29-77		15.00	381.00	1.12	28.58	X	
12-31-77		15.50	393.70	0.25	6.35	X	
1- 3-78		16.00	406.40	0.17	4.23	X	
1- 6-78		18.00	457.20	0.67	16.93	2.88	0.88
12-12-77	100'	9.00	228.60			3.67	1.12
12-22-77		12.00	304.80	0.30	7.62	X	
12-27-77		15.50	393.70	0.70	17.78	X	
12-29-77		17.50	440.50	1.00	25.40	X	
12-31-77		18.50	469.90	0.50	12.70	X	
1- 3-78		18.75	476.25	0.08	2.12	X	
1- 6-78		18.75	476.25	0	0	X	

OTTAUQUECHEE RIVER

Sta. 30+00

Date	Position* from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-22-77	40'	8.00	203.20				
12-31-77		15.00	381.00	0.78	19.76	X	
1- 3-78		15.75	400.05	0.25	6.35	X	
1- 6-78		16.25	412.75	0.17	4.23	X	
12-22-77	100'	8.00	203.20				
12-31-77		15.38	390.65	0,82	20.83	X	
1- 3-78		15.38	390.65	0	0	X	
1- 6-78		16.00	406.40	0.21	5.25	X	

OTTAUQUECHEE RIVER

Sta. 31+00

Date	Position* from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-12-77	75'	7.00	177.80			5.83	1.78
12-13-77		10.25	260.35	3.25	82.55	5.83	1.78

OTTAUQUECHEE RIVER

Sta. 37+00

Date	Position* from lt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-12-77	20'	3.25	82.55			0	
12-13-77		3.50	88.90	0.25	6.35	0	
12-21-77		7.25	184.15	0.47	11.91	0	
12-27-77		10.25	260.35	0.67	16.93	0	
12-29-77	35'	12.25	311.15			0	
1- 3-78		14.50	368.30	0.45	11.43	0	
1- 6-78		15.00	381.00	0.17	4.23	0	
12-12-77	70'	3.50	88.90			X	
12-21-77		7.50	190.50	0.44	11.29	4.06	1.24
12-27-77		11.00	279.40	0.58	14.82	X	
12-29-77		12.00	304.80	0.50	12.70	X	
1- 3-78		12.50	317.50	0.10	2.54	X	
1- 6-78		14.50	368.30	0.67	16.93	X	

Sta. 37+00 (cont'd)

12-12-77	105'	3.50	88.90				
12-21-77		7.00	177.80	0.39	9.88	1.70	0.52
12-29-77		12.00	304.80	0.62	15.88	X	
1- 3-78		12.25	311.15	0.05	1.27	X	
1- 6-78		14.75	374.65	0.83	21.17	X	
12-21-77	115'	7.00	177.80			1.70	0.52
12-29-77		11.50	292.10	0.56	14.29	X	
1- 3-78		12.00	304.80	0.10	2.54	0	
1- 6-78		14.00	355.60	0.67	16.93	X	

OTTAUQUECHEE RIVER

Sta. 45+00

Date	Position* from lt.	Ice thickness in.	mm	Growth rate in./day	mm/day	Slush ice ft	m
12-12-77	35'	3.50	88.90			0	
12-13-77		3.50	88.90	0	0	0	
12-22-77		6.50	165.10	0.33	2.47	X	
12-27-77		16.00	406.40	1.90	48.26	0	
12-29-77		18.00	457.20	1.00	25.40	X	
1- 3-78		18.00	457.20	0	0	0	
1- 6-78		19.25	488.95	0.42	10.58	X	
12-12-77	70'	3.25	82.55			0	
12-22-77		6.50	165.10	0.32	8.25	X	
12-27-77		11.00	279.40	0.90	22.86	0	
12-29-77		13.00	330.20	1.00	25.40	X	
1- 3-78		14.50	368.30	0.30	7.62	X	
1- 6-78		15.25	387.35	0.25	6.35	X	
12-12-77	105'	3.00	76.20			X	
1- 3-78		22.00	558.80	0.86		X	
1- 6-78		22.50	571.50	0.17	4.23	X	

OTTAUQUECHEE RIVER

Sta. 49+00

Date	Position* from lt.	Ice thickness in.	mm	Growth rate in./day	mm/day	Slush ice ft	m
12-27-77	35'	8.50	215.90			X	
1- 3-78		11.75	298.45	0.46	11.79	0	
1- 6-78		14.50	368.30	0.92	23.28	0	

Sta. 49+00 (cont'd)

Date	Position* from lt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-27-77	70'	8.50	215.90			X	
12-29-77		13.75	349.25	2.62	66.68	X	
1- 3-78		14.00	355.60	0.05	1.27	X	
1- 6-78		17.00	431.80	1.00	25.40	X	
12-27-77	105'	8.00	203.20			0	
12-29-77		10.38	263.65	1.19	30.23	X	
1- 3-78		15.25	387.35	0.97	24.74	0	
1- 6-78		16.50	419.10	0.42	10.58	0	

OTTAUQUECHEE RIVER

Sta. 53+00

Date	Position* from lt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m
12-27-77	35'	10.75	273.05			X	
12-29-77		13.00	330.20	1.12	28.58	X	
1- 3-78		14.00	355.60	0.20	5.08	0	
1- 6-78		14.75	374.65	0.25	6.35	0	
12-22-77	55'	4.00	101.60			X	
12-27-77		8.00	203.20	0.80	20.32	0	
12-29-77		11.00	279.40	1.50	38.10	X	
1- 3-78		14.75	374.65	0.75	19.05	X	
12-22-77	70'	4.00	101.60			X	
12-27-77		6.00	152.40	0.40	10.16	X	
12-29-77		9.00	228.60	1.50	38.10	X	
1- 6-78		18.25	463.55	1.16	29.37	X	
12-22-77	110'	4.00	101.60			X	
1- 3-78		9.00	228.60	0.42	10.58	X	
1- 6-78		11.50	292.10	0.83	21.17	X	

APPENDIX B: ICE THICKNESS DATA, OTTAUQUECHEE RIVER, THIRD FREEZE-UP.

Sta. 25+70

Date	Position from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m	Snow cover ft	Snow cover m
2-23-78	17'	18.50	469.90			2.30	0.70		
3- 2-78		20.50	520.70	0.28	7.26	X			
3- 9-78		23.75	603.25	0.46	11.79	X		0.17	0.05
3-14-78		24.50	622.30	0.15	3.81	X			
3-20-78		24.00	609.60	-0.08	-2.12				
3-22-78		20.00	508.00	-2.00	-50.80				
2- 1-78	35'	5.75	146.05			X			
2- 6-78		13.25	336.55	1.50	38.10				
2- 1-78	90'	13.00	330.20			X			
2- 6-78		16.00	406.40	0.60	15.24	X			
2-23-78	105'	32.50	825.50			1.72	0.52		
3- 2-78		33.50	850.90	0.14	3.63	X			
3- 9-78		33.50	850.90	0	0	X		0.17	0.05
3-14-78		32.25	819.15	-0.25	-6.35	X			
2- 1-78	170'	9.50	241.30			X			
2- 6-78		16.00	406.40	1.30	33.02	X			

OTTAUQUECHEE RIVER

Sta. 27+00

Date	Position from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m	Snow cover ft	Snow cover m
2- 1-78	40'	12.00	304.80			X			
2- 6-78		17.00	431.80	1.00	25.40	X			
3- 2-78		27.00	685.80	0.42	10.58	X			
3- 9-78		31.50	800.10	0.64	16.33	X		0.25	0.08
3-14-78		34.25	869.95	0.55	13.97	X			
3-20-78		29.00	736.60	-1.05	-26.67				
3-24-78		26.00	660.40	-0.75	-19.05				
2- 1-78	90'	6.50	165.10			0			
2- 6-78		12.25	311.15	1.15	29.21	X			

OTTAUQUECHEE RIVER

Sta. 30+00

Date	Position from lt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m	Snow cover ft	Snow cover m
2- 1-78	70'	9.50	241.30			5.00	1.52		
2- 6-78		10.25	260.35	0.15	3.81	X			
2-16-78		16.00	406.40	0.58	14.60	X			
3- 2-78		21.00	533.40	0.38	9.07	X		0.75	0.23
3- 9-78		21.75	552.45	0.11	2.72	X		0.50	0.15
3-14-78		21.00	533.40	-0.15	-3.81	X			
3-20-78		21.00	533.40	0		X			
3-24-78		20.50	520.70	-0.12	-3.18				

OTTAUQUECHEE RIVER

Sta. 37+00

Date	Position from lt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m	Snow cover ft	Snow cover m
2- 1-78	25'	4.50	114.30						
2- 6-78		11.00	279.40	1.30	33.02				
2-16-78		17.00	431.80	0.60	15.24				
2-23-78		20.00	508.00	0.43	10.88				
3- 2-78		26.25	666.75	0.89	22.68				
3- 9-78		26.00	660.40	-0.04	-0.91				
3-14-78		24.00	609.60	-0.40	-10.16				
3-20-78		15.00	381.00	-1.50	-38.10				
2- 1-78	65'	6.00	152.40			X			
2- 6-78		13.00	330.20	1.40	35.56	X			
2-16-78		16.75	425.45	0.38	9.52	X			
2-23-78		18.25	463.55	0.21	5.44	X			
3- 2-78		20.50	520.70	0.32	8.16	X			
3- 9-78		20.00	508.00	-0.07	1.81	X		0.50	0.15
3-14-78		20.00	508.00	0		X			
3-20-78		20.00	508.00	0		X			
2- 1-78	105'	6.00	152.40			X			
2- 6-78		13.50	342.90	1.50	38.10	X			
2-16-78		17.00	431.80	0.35	8.89	X			
2-23-78		24.00	609.60	1.00	25.40	X			
3- 2-78		26.00	660.40	0.28	7.26				
3- 9-78		25.75	654.05	-0.04	-0.91				
3-14-78		23.50	596.90	-0.45	-11.43				
3-20-78		23.50	596.90	0					

OTTAUQUECHEE RIVER

Sta. 38+00

Date	Position from lt.	Ice thickness in.	mm	Growth rate in./day	mm/day	Slush ice ft	m	Snow cover ft	m
3- 9-78	31'	16.00	406.40						
3-14-78		15.50	393.70	-0.10	-2.54				
3-22-78		13.00	330.20	-0.31	-7.94				
3-24-78		8.50	215.90	-2.25	-57.15				
2-23-78	41'	24.00	609.60						
3- 9-78		19.00	482.60	-0.36	-9.07	X			
3-14-78		19.00	482.60	0		X			
3-22-78		19.00	482.60	0					
3-24-78		19.00	482.60	0		X			
2-23-78	56'	21.00	533.40						
2- 9-78		21.25	539.75	0.02	0.45				
2-14-78		20.00	508.00	-0.25	-6.35				
3- 9-78	62'	22.75	577.85						
3-14-78		16.00	406.40	-1.35	-34.29				
2-23-78	71'	18.00	457.20						
3- 9-78		19.75	501.65	0.12	3.18				
3-14-78		18.00	457.20	-0.35	-8.89				
3- 9-78	86'	21.00	533.40			X			
3-14-78		20.00	508.00	-0.20	-5.08	X			
2-23-78	116'	20.50	520.70			X			
3- 9-78		17.50	444.50	-0.21	-5.44	X			
3-14-78		17.50	444.50	0		X			
2-23-78	136'	20.00	508.00			X			
3- 9-78		26.50	673.10	0.46	11.79				
3-14-78		21.50	546.10	-1.00	-25.40				

OTTAUQUECHEE RIVER

Sta. 45+00

Date	Position from lt.	Ice thickness in.	mm	Growth rate in./day	mm/day	Slush ice ft	m	Snow cover ft	m
2- 1-78	35'	5.50	139.70			X			
2- 6-78		12.75	323.85	1.45	36.83				
2-16-78		16.75	425.45	0.40	10.16	X			
3- 2-78		27.50	698.50	0.77	19.50	X			
3- 9-78		27.50+	Ice Grounded						
3-14-78		27.50+	" "						

Sta. 45+00 (cont'd)

2- 1-78	70'	0.88	22.35			X	
2- 6-78		8.25	209.55	1.47	37.44		
2-16-78		12.00	304.80	0.38	9.52		
2-23-78		18.25	463.55	0.89	22.68		
3- 2-78		27.00	685.80	1.25	31.75		
3- 9-78		25.50	647.70	-0.21	-5.44		
3-14-78		21.50	546.10	-0.80	-20.32		
2- 6-78	105'	11.75	298.45			X	
2-16-78		16.00	406.40	0.42	10.80	X	
2-23-78		21.25	539.75	0.75	19.05	X	
3- 2-78		23.75	603.25	0.36	9.07	X	
3- 9-78		22.50	571.50	-0.18	-4.54		

OTTAUQUECHEE RIVER

Sta. 49+00

Date	Position from lt.	Ice thickness		Growth rate		Slush ice		Snow cover	
		in.	mm	in./day	mm/day	ft	m	ft	m
2-16-78	10'	18.00	457.20			1.42	0.43		
2-23-78		21.50	546.10	0.50	12.70				
2-16-78	20'	11.50	292.10						
2-23-78		11.50	292.10						
3- 2-78		13.00	330.20	0.21	5.44				
3- 9-78		16.25	412.75	0.46	11.79			0.25	0.08
3-14-78		15.25	387.35	-0.20	-5.08				
3-20-78		13.50	342.90	-0.29	-7.41				
3-22-78		9.25	234.95	-2.12	-53.98				
3-23-78		8.50	215.90	-0.75	-19.05				
2-16-78	28'	9.00	228.60						
2-23-78		12.50	317.50	0.50	12.70				
3- 2-78		14.00	355.60	0.21	5.44				
3- 9-78		18.25	463.55	0.61	15.42				
3-14-78		15.00	381.00	-0.65	-16.51				
3-20-78		10.00	254.00	-0.83	-21.17				
3-22-78		7.00	177.80	-1.50	-38.10				
3-23-78		6.00	152.40	-1.00	-25.40				
2- 6-78	37'	6.75	171.45			X			
2-16-78		8.75	222.25	0.20	5.08				
2-23-78		11.50	292.10	0.39	9.98.				
3- 2-78		12.00	304.80	0.07	1.81				
3- 9-78		15.50	393.70	0.50	12.70				
3-14-78		13.25	336.55	-0.45	-11.43				
3-20-78		7.00	177.80	-1.04	-26.46				
3-22-78		7.00	177.80	0					
3-23-78		6.25	158.75	-0.75	-19.05				

Sta. 49+00 (cont'd)

2-16-78	47'	9.50	241.30			2.95	0.90		
2-23-78		11.50	292.10	0.29	7.26				
3- 2-78		12.25	311.15	0.11	2.72				
3- 9-78		14.00	355.60	0.25	6.35				
3-14-78		11.75	298.45	-0.45	-11.43				
3-20-78		7.00	177.80	-0.79	-20.11				
3-22-78		6.00	152.40	-0.50	-12.70				
3-23-78		5.00	127.00	-1.00	-25.40				
2-23-78	54'	11.00	279.40						
3- 2-78		12.50	317.50	0.21	5.44				
3- 9-78		13.50	342.90	0.14	3.63			0.17	0.05
3-14-78		11.50	292.10	-0.40	-10.16				
3-20-78		10.25	260.35	-0.21	-5.29				
3-22-78		10.00	254.00	-0.12	-3.18				
3-23-78		9.50	241.30	-0.50	-12.70				
3- 2-78	58'	14.50	368.30	0.09	2.25			0.17	0.05
3- 9-78		15.12	384.05	-0.42	-10.77				
3-14-78		13.00	330.20	-0.33	-8.47				
3-22-78		10.00	254.00	-0.50	-12.70				
3-23-78		9.25	234.95	-0.75	-19.05				
3-24-78		9.00	228.60	-0.25	-6.35				
3-25-78		7.00	177.80	-2.00	-50.80				
2-16-78	61'	9.00	288.60			2.94	0.98		
2-23-78		14.00	355.60	0.71	18.14	X			
3- 2-78		19.00	482.60	0.71	18.14				
3- 9-78		18.50	469.90	-0.07	-1.81			0.17	0.05
3-14-78		15.50	393.70	-0.60	-15.24				
3-20-78		13.00	330.20	-0.42	-10.58				
3-22-78		12.00	304.80	-0.50	-12.70				
3-23-78		11.50	292.10	-0.50	-12.70				
3-24-78		10.50	266.70	-1.00	-25.40				
3-25-78		9.00	228.60	-1.50	-38.10				
2-16-78	74'	10.75	273.05			2.83	0.86		
2-23-78		14.00	355.60	0.46	11.79	X			
3- 2-78		16.50	419.10	0.36	9.07	X			
3- 9-78		16.75	501.65	0.46	11.79	X		0.17	0.05
3-14-78		19.00	482.60	-0.15	-3.81	X			
3-20-78		19.00	482.60	0		X			
3-22-78		18.75	476.25	-0.12	-3.18				
3-23-78		18.50	469.90	-0.25	-6.35				
3-24-78		14.50	368.30	-4.00	-101.60				
3-25-78		12.00	304.80	-2.50	-63.50				

Sta. 49+00 (cont'd)

Date	Position from lt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m	Snow cover ft	Snow cover m
2- 6-78	96'	7.00	177.80			X			
2-16-78		16.62	422.15	0.96	24.43	2.20	0.67		
2-23-78		16.75	425.45	0.02	0.47	X			
3- 2-78		18.00	457.20	0.18	4.53	X			
3- 9-78		20.50	520.70	0.21	5.44	X		0.08	0.02
3-14-78		20.00	508.00	-0.10	-2.54	X			
3-20-78		18.75	476.25	-0.21	-5.29				
3-22-78		15.00	381.00	-1.88	-47.62				
3-23-78		13.50	342.90	-1.50	-38.10				
3-24-78		11.00	279.40	-2.50	-63.50				
3-25-78		9.00	338.60	-2.00	-50.80				
2-16-78	118'	16.00	406.40			1.75	0.53		
2-23-78		21.00	533.40	0.71	18.14	X			
3- 2-78		21.00	533.40	0		X			
3- 9-78		22.00	558.80	0.14	3.63	X			
3-14-78		22.00	558.80	0		X			
3-20-78		20.00	508.00	-0.33	-8.47				
3-22-78		13.50	342.90	-3.25	-82.55				
3-23-78		11.50	292.10	-2.00	-50.80				
3-24-78		10.00	254.00	-1.50	-38.10				
3-25-78		7.00	177.80	-3.00	-76.20				
2- 6-78	142'	7.00	177.80						
2-16-78		15.75	400.05	0.88	22.22	2.31	0.70		
2-23-78		20.50	520.70	0.68	17.24	X			
3- 2-78		25.00	635.00	0.64	16.33	X			
3- 9-78		25.00	635.00	0		X			
3-14-78		22.00	558.80	-0.60	-15.24				
3-20-78		18.00	457.20	-0.67	-16.93				
3-22-78		9.50	241.30	-4.25	-107.95				
3-23-78		8.50	215.90	-1.00	-25.40				

OTTAUQUECHEE RIVER

Sta. 50+50

Date	Position from lt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m	Snow cover ft	Snow cover m
2-16-78	40'	14.50	368.30						
2-23-78		14.50	368.30	0					
3- 2-78		14.75	374.65	0.04	0.91				
3- 9-78		16.75	425.45	0.29	7.26			0.25	0.08
3-14-78		13.75	349.25	-0.60	-15.24				
3-20-78		6.75	171.45	-1.17	-29.63				

Sta. 50+50 (cont'd)

2-16-78	50'	10.50	266.70			X			
2-23-78		12.50	317.50	0.29	7.26				
3- 2-78		14.00	355.60	0.21	5.44				
3- 9-78		14.50	368.30	0.07	1.81			0.25	0.08
3-14-78		11.00	279.40	-0.70	-17.78				
3-20-78		10.00	254.00	-0.20	-5.08				
3-22-78		9.50	241.30	-0.25	-6.35				
2-16-78	52'	10.50	266.70			X			
2-23-78		17.00	431.80	0.93	23.59	X			
3- 2-78		16.00	406.40	-0.14	-3.63				
3- 9-78		15.75	400.05	-0.04	-0.91			0.25	0.08
3-14-78		12.25	311.15	-0.70	-17.78				
3-20-78		12.00	304.80	-0.04	-0.91				
3-22-78		11.00	279.40	-0.50	-12.70				
3-23-78		10.00	254.00	-1.00	-25.40				
2-16-78	55'	15.00	381.00			X			
2-23-78		18.75	476.25	0.54	13.61	X			
3- 2-78		20.00	508.00	0.18	4.54	X			
3- 9-78		20.50	520.70	0.07	1.81				
3-14-78		15.50	393.70	-1.00	-25.40				
3-20-78		13.50	342.90	-0.33	-8.47				
3-22-78		13.50	342.90	0					
3-23-78		12.50	317.50	-1.00	-25.40				
3- 9-78	60'	17.00	431.80			X		0.33	0.10
3-14-78		17.00	431.80	0					
3-20-78		16.00	406.40	-0.17	-4.23				
3-22-78		14.00	355.60	-1.00	-25.40				
3-23-78		13.25	336.55	-0.75	-19.05				
3-14-78	65'	14.75	374.65			X			
3-20-78		13.50	342.90	-0.21	-5.29				
3-22-78		13.00	330.20	-0.25	-6.35				
3-23-78		12.00	304.80	-1.00	-25.40				

OTTAUQUECHEE RIVER

Sta. 53+00

Date	Position from lt.	Ice thickness in.	mm	Growth rate in./day	mm/day	Slush ice ft	m	Snow cover ft	m
2- 6-78	40'	6.75	171.45			X			
2-16-78		7.50	190.50	0.08	1.90	X			
2-23-78		12.50	317.50	0.71	18.14	4.78	1.44		
3- 2-78		16.00	406.40	0.50	12.70	X			
3- 9-78		17.00	431.80	0.14	3.63	X		0.25	0.08
3-14-78		18.75	476.25	0.35	8.89	X			
3-20-78		17.75	450.85	-0.20	-5.08	X			
3-22-78		17.50	450.85	0					
3-23-78		16.00	406.40	-1.50	-38.10	X			
3-24-78		16.00	406.40	0		X			

Sta. 53+00 (cont'd)

2- 6-78	75'	6.75	171.45						
2-16-78		8.00	203.20	0.12	3.18	X			
2-23-78		12.50	317.50	0.64	16.33	3.36	1.02		
3- 2-78		15.00	381.00	0.36	9.07	X			
3- 9-78		17.75	450.85	0.39	9.98	X		0.25	0.08
3-14-78		17.00	431.80	-0.15	-3.81	X			
3-20-78		15.25	387.35	-0.29	-7.41	X			
3-22-78		15.25	387.35	0					
3-23-78		13.50	342.90	-1.75	-44.45				
3-24-78		11.00	279.40	-2.50	-63.50				
3- 2-78	90'	16.00	406.40			X			
3- 9-78		17.25	438.15	0.18	4.54	X		0.25	0.08
3-14-78		18.25	463.55	0.20	5.08	X			
3-20-78		19.00	482.60	0.12	3.18	X			
3-22-78		17.50	444.50	-0.75	-19.05				
3-23-78		15.00	381.00	-2.50	-63.50				
3-24-78		15.00	381.00	0					
2-16-78	100'	8.50	215.90			X			
3- 2-78		16.25	412.75	0.55	14.06	X			
3- 9-78		19.25	488.95	0.43	10.88	X		0.25	0.08
3-14-78		19.75	501.65	0.10	2.54	X			
3-20-78		19.50	495.30	-0.04	-1.06	X			
3-22-78		17.75	450.85	-0.88	-22.22	X			
3-23-78		17.75	450.85	0					
3-24-78		17.75	450.85	0					
2- 6-78	115'	6.75	171.45						
2-16-78		7.50	190.50	0.08	1.90	X			
2-23-78		15.50	393.70	1.14	29.03	3.43	1.04		
3- 2-78		16.25	412.75	0.11	2.72	X			
3- 9-78		19.00	482.60	0.39	9.98				
3-14-78		18.50	469.90	-0.10	-2.54				
3-20-78		17.25	438.15	-0.21	-5.29				
3-22-78		16.50	419.10	-0.38	-9.52				
3-23-78		13.00	330.20	-3.50	-88.90				
2-16-78	130'	4.00	101.60			X			
2-23-78		12.00	304.80	1.14	29.03				

APPENDIX C: ICE THICKNESS DATA, WINOOSKI RIVER.

Middlesex Sta. 25+25

Date	Position from lt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m	Snow cover ft	Snow cover m
1-16-78	35'	6.00	152.40						
1-28-78		12.50	317.50	0.54	13.76	X			
2-17-78		20.50	520.70	0.47	11.95	X			
2-28-78		28.00	711.20	0.68	17.32	5.28	1.61		
2-17-78	15'	8.00	203.20						
2-28-78		26.00	660.40	1.64	41.56				
1-16-78	85'	5.00	127.00						
1-28-78		11.00	279.40	0.50	12.70	X			
2-17-78		24.00	609.60	0.76	19.42	1.94	0.59		
2-28-78		25.00	635.00	0.09	2.31	1.82	0.56		
1-16-78	130'	4.00	101.60						
2-17-78		14.50	368.30	0.36	9.20	0.96	0.29		
2-28-78		17.00	431.80	0.23	5.77				

Middlesex Sta. 45+00
Montpelier Sta. 1+00

1-28-78	35'	11.00	279.40			X			
2-17-78		13.75	349.25	0.16	4.11				
2-28-78		15.75	400.05	0.18	4.62				
1-28-78	70'	8.75	222.25			X			
2-17-78		10.00	254.00	0.07	1.87				
2-28-78		12.00	304.80	0.18	4.62				
2-17-78	105'	11.50	292.10			2.65	0.81		
2-28-78		13.25	336.55	0.16	4.06	2.93	0.89		

WINOOSKI RIVER

Middlesex Sta. 37+50

Date	Position from rt.	Ice thickness in.	Ice thickness mm	Growth rate in./day	Growth rate mm/day	Slush ice ft	Slush ice m	Snow cover ft	Snow cover m
1-16-78	40'	5.00	127.00			X			
1-28-78		10.00	254.00	0.42	10.58				
2-17-78		12.00	304.80	0.12	2.99				
2-28-78		12.00	304.80	0					

Middlesex Sta. 37+50 (cont'd)

2-17-78	70'	14.50	368.30			X	
2-28-78		18.00	457.20	0.32	8.08	3.55	1.08

Middlesex Sta. 32+00

1-16-78	25'	5.75	146.05			X	
2-17-78		15.25	387.35	0.33	8.32	X	
2-28-78		17.25	438.15	0.18	4.62		
1-16-78	55'	4.50	114.30			X	
2-17-78		14.75	374.65	0.35	8.98		
2-28-78		16.25	412.75	0.14	3.46		
1-16-78	80'	5.00	127.00			X	
2-17-78		17.50	444.50	0.43	10.95		
2-28-78		17.50	444.50	0			

Middlesex Sta. 26+50

1-16-78	30'	7.00	177.80			X	
1-28-78		13.00	330.20	0.50	12.70	X	
2-17-78		19.00	482.60	0.35	8.96	1.37	0.42
2-28-78		19.00	482.60	0			
1-16-78	65'	5.00	127.00			X	
1-28-78		13.25	336.55	0.69	17.46	X	
2-17-78		20.50	520.70	0.43	10.83	3.80	1.16
2-28-78		23.50	596.90	0.27	6.93	3.12	0.95
1-16-78	110'	7.50	190.50			X	
2-17-78		17.25	438.15	0.34	8.54	X	
2-28-78		23.00	584.20	0.52	13.28	3.92	1.19

WINOOSKI RIVER

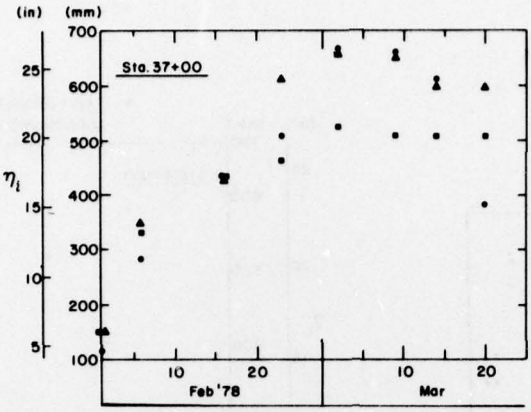
Montpelier Sta. 7+00

2-17-78	35'	10.75	273.05				
2-28-78		13.00	330.20	0.20	5.20		
2-17-78	70'	12.75	323.85			3.33	1.02
2-28-78		17.25	438.15	0.41	10.39	3.22	0.98
2-17-78	105'	12.75	323.85			2.58	0.79
2-28-78		12.75	323.85	0		2.55	0.78

Montpelier Sta. 10+00

1-28-78	30'	5.00	127.00		Holes were not drilled	
2-17-78		24.00	609.60		in the same locations.	
2-28-78		22.25	565.15			
1-28-78	60'	5.00	127.00			
2-17-78		17.00	431.80	0.47	17.93	X
2-28-78		16.25	412.75	Not in same location		X
1-28-78	90'	5.00	127.00			
2-17-78		13.00	330.20	0.47	11.95	
2-28-78		15.75	400.05	0.25	6.35	
2-17-78	100'	12.75	323.85			X
2-28-78		19.00	482.60	0.57	14.43	X

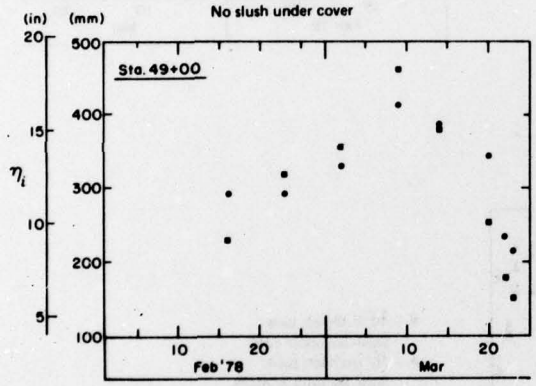
APPENDIX D: GRAPHS OF ICE THICKNESS DURATION, THIRD FREEZE-UP.



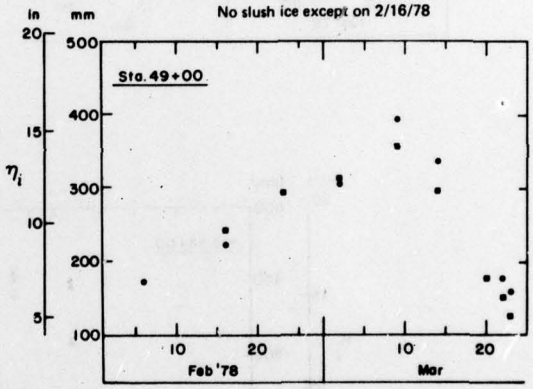
OTTAUQUECHEE RIVER
STATION 37+00

● – 25′ from left bank
No slush ice under cover
■ – 65′ from left bank
Slush ice under cover
▲ – 105′ from left bank
Slush ice under cover until 3/2/78

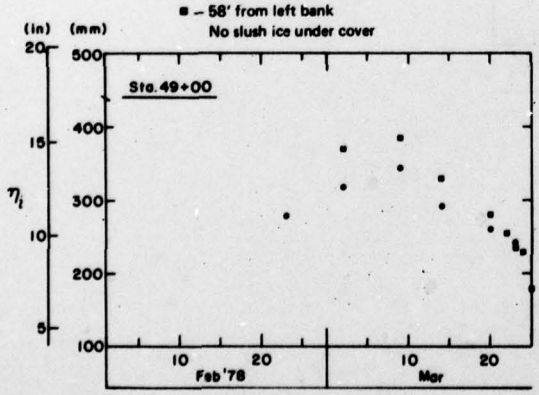
● – 20′ from left bank
No slush under cover
■ – 28′ from left bank
No slush under cover



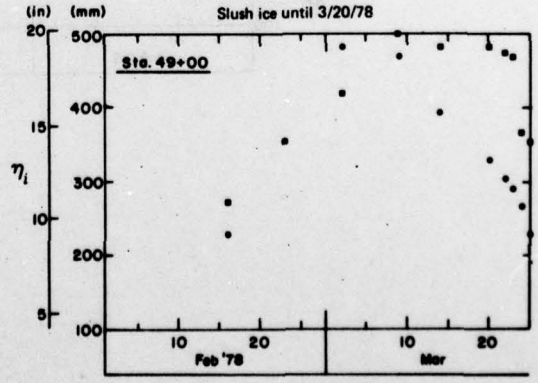
● – 37′ from left bank
No slush ice except on 2/6/78
■ – 47′ from left bank
No slush ice except on 2/16/78

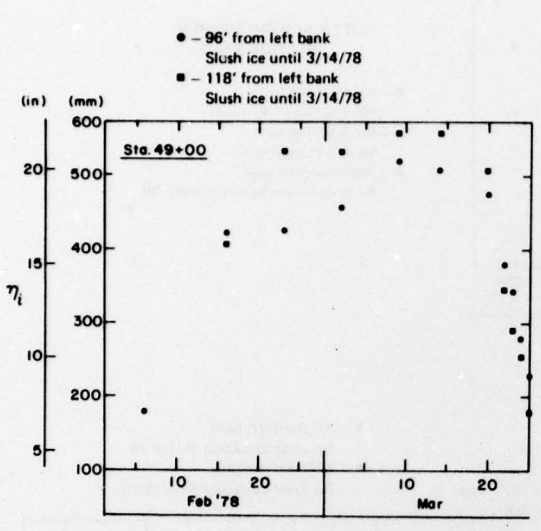


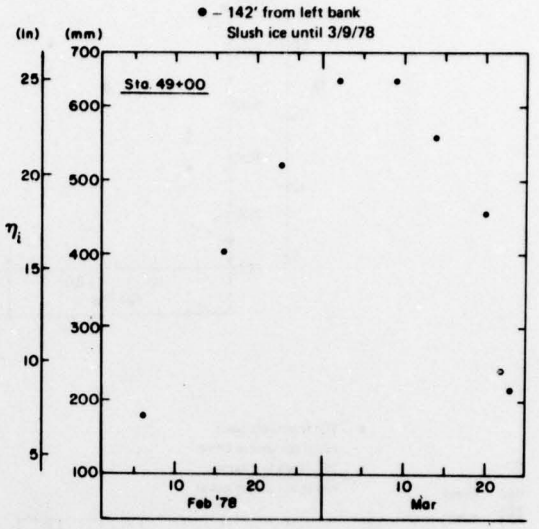
● – 54′ from left bank
No slush ice under cover
■ – 58′ from left bank
No slush ice under cover

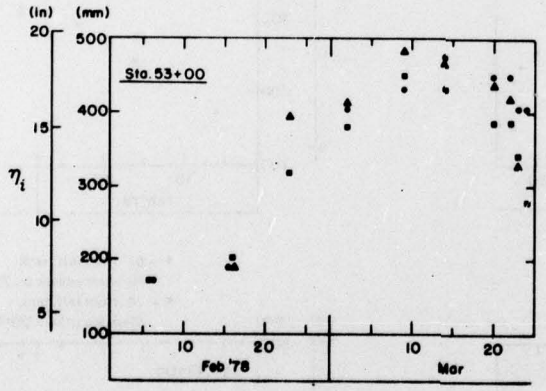


● – 61′ from left bank
No slush except on 2/16 and 2/23/78
■ – 74′ from left bank
Slush ice until 3/20/78









● – 40' from left bank
Slush ice under cover
■ – 75' from left bank
Slush ice until 3/20/78
▲ – 115' from left bank
Slush ice until 3/2/78